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DRUM ATOMISATION STUDIES

by

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### S u m m a r y

Studies have been made into the behaviour of rotating drums as a means of atomisation and fuel injection for gas turbine engines. Radial holes in the wall of the drum discharge liquid continuously, forming jets which atomise on contact with the surrounding air. The effects of rotational speed, drum diameter, liquid flow rate and hole proportions have been investigated using water and kerosine. The flow and atomisation characteristics have been established and are discussed in terms of application to the gas turbine. It is apparent that savings in complexity, weight and hence cost of fuel systems may be achieved with drum atomisers, but these may be offset to some extent by the increased costs of full scale annular combustion chamber development.

## 1.0 Introduction

From time to time the design and development of different types of gas turbine engine have led to problems, associated with the conventional swirl type atomiser, which have only been overcome by introducing mechanical complexity into the atomiser and fuel system. Whereas reliable working solutions have always been found in the past, these solutions have generally increased the cost and weight of the engine. Probably the prime reason for most of these problems is a basic limitation of the swirl type atomiser. This limitation revolves around its inability to produce fine sprays at low fuel flows combined with a satisfactory operating pressure at the maximum flow demand. The introduction of the Duplex or Duple type atomiser is an example of a solution to this problem. However, in the application of modern light-weight lift engines to vertical take-off aircraft where a large number of engines may be required, the solution quoted may be very costly and detrimental to overall performance.

The introduction of a centrifugal type of atomiser on some French engines and the development of similar systems in this country around 1959/60 has led to considerable interest in this unconventional means of fuel injection. One may speculate as to the advantages of this type of atomiser over the swirl type when applied to light lift engines. However, a lack of knowledge of this type of atomiser was the first stimulus for the work carried out in the Propulsion Department at the College of Aeronautics, Cranfield. The studies undertaken over the past three years have been confined to experimental investigations of flow and atomising characteristics of drum type atomisers. This report describes these investigations and discusses briefly the application of the drum atomiser.

## 2.0 Scope of Studies

Initially, very little being known about the behaviour of these centrifugal systems, it was anticipated that a large number of



factors would influence their performance. The variables which were considered to be of importance for a systematic study were:-

- (a) Rotational speed
- (b) Drum diameter
- (c) Liquid flow rate
- (d) Discharge nozzle proportions
- (e) Discharge liquid properties

The extent to which these variables could be changed in any particular configuration was obviously limited. Nevertheless, attempts were made to adjust the range of each variable to lie within conditions existing on present-day engines.

Rotational speeds were varied up to 40,000 r.p.m., drum diameters from 1.7 to 6.0 inches and discharge rates up to 70 gal/hr. Several nozzle diameters were investigated in the range  $1/32"$  to 2 mm., with length/diameter ratios ranging from 3.2 to 34. Two liquids were studied - water and aviation kerosine.

Although no basic atomisation theory was available for predicting the effect of variables on the sprays produced by the drum atomiser, it was felt that a process similar to spinning disc atomisation would be present. In this respect the work of Walton & Prewett, reference (1), has provided a good guide to the effects of some of the variables. In addition, the work of Nukiyama & Tanasawa, reference (2), on air-blast atomisation, indicated suitable means of correlating the atomiser's performance.

### 3.0 Apparatus and techniques

The experimental facilities used in studying the behaviour of the drum atomiser are shown diagrammatically in Fig.1. They consist essentially of the drum atomiser assembly, details of which are shown in Fig.2. The rotating shaft, driven by a simple air impulse turbine capable of attaining speeds of 40,000 r.p.m., is supported on angular contact bearings contained in a mild steel case and mounted on a sturdy test stand.



Lubrication of the bearings is provided by a Norgren air mist system. Liquid is delivered into one end of the hollow shaft of the atomiser from an air pressurised tank via a continuous flow rotameter and a Flexi-Box rotary seal. The liquid is atomised at the opposite end of the shaft by centrifuging through a number of small radial drillings. The speed of rotation of the atomiser is detected with the aid of a small capacity pick-up located in the wall of the atomiser assembly casing. Capacity changes from the pick-up are converted into voltage impulses, divided and displayed on a digital frequency meter. A further synchronous signal is fed to an Ernest-Turner Stroboscopic lamp used for observing the spray formation and photography. When in operation the atomiser is surrounded by a 2.5 ft. x 2.5 ft. spray-containing chamber and observations are made vertically above the atomiser.

To facilitate observations of the flow within the rotating system, each type of drum used had provision for an observation window. Initially, two steel drums were manufactured - 1.7 ins. diameter and 3.4 ins. diameter. Later a 6 inch diameter aluminium drum of different internal proportions was adapted to the rotating shaft, which enabled simple modifications to be made to the drum in order to study 4 inch and 2 inch diameter systems with the same internal configuration (see Fig.3).

### 3.1 Droplet sampling

The droplets in a given mist were collected on magnesium oxide coated glass slides. Over a wide range of rotational speeds the slides were waved through the spray produced on the plane of atomisation. The impaction of the droplet on the magnesium oxide coating left a permanent impression in proportion to the actual droplet size. K.R. May (ref.7) has calibrated magnesium oxide for the collection of liquid droplets. Although this technique was inefficient in collecting the very small droplets present, the results obtained were conservative in estimating spray quality expressed in Sauter Mean Diameter. In the majority of cases slides were taken at different radii for a fixed operating



condition of the atomiser to overcome any error due to non-representative sampling.

### 3.2 Liquid discharge velocity measurement

The liquid discharge velocity was estimated from a knowledge of the instantaneous path of the liquid jet leaving the drum. This information can be obtained by observing the jet under stroboscopic conditions. A typical photograph of such an observation is shown in Fig.4. It should be realised that the velocity of particles of liquid along the curved path are in a direction perpendicular to the path. If there is no radial component of velocity in the liquid leaving the nozzle, the curved path would be a perfect involute. A radial component of velocity in the liquid modifies the path. Hence, by comparison, an estimation of radial velocity can be achieved.

A camera with tele-photo lens mounted directly above the atomiser was set up to photograph jet paths when liquid discharge velocities were investigated. Exposures of 1 second were sufficient to give clear pictures when daylight was excluded from stroboscopic illumination. At high total liquid flow rates, observations became difficult due to the large quantities of mist produced. In order to make estimations for these conditions the number of nozzles was reduced and in some cases only one nozzle was used.

## 4.0 Results

The work of Holmes, (ref.5), covers investigations into liquid discharge velocity and spray quality for two drum sizes, 1.7 ins. and 3.4 ins. diameter, over a wide range of conditions. In addition, observations of internal flow and jet break-up were made stroboscopically. The work of Ajvas (ref.6) was confined mainly to the effect of variables on atomiser flow rate. Since it would be lengthy to relate details of these investigations, the results will be summarised here and more relevant points discussed.

### 4.1 Internal Flow Observations

The rotational speed, liquid flow rate, and whether the shaft was accelerating or decelerating were the factors which influenced the



internal flow behaviour.

At low flow rates, less than 12 gals/hr., a simple type of vortex flow was established which was independent of rotational speed. Above the flow rate of 12 gals/hr. the vortex flow still existed at low rotational speeds but at a critical speed, which depended on flow rate, an unusual type of flow was established. This phenomenon appeared as a fountain of liquid passing up through the drum with an air annulus surrounding it. After the liquid fountain impinged on the window of the drum, the flow passed radially outwards through the nozzles. The inclusion of a diametral splitter plate low down in the atomiser eliminated the fountain flow phenomena.

#### 4.2 Stroboscopic observations of discharging liquid

From stroboscopic photographs, e.g. Fig.4, liquid discharge velocities were estimated for a wide range of rotational speeds and flows. It was found that only a 7% increase in flow velocity over the tangential velocity was measured at the highest rotational speed and flow rate. (See Fig.5). The reason for this investigation was the elimination of an unknown variable, radial jet velocity, in any subsequent attempts to correlate spray quality with jet velocity.

#### 4.3 Flow characteristics

The work of Ajvas has shown that the flow characteristics of the drum atomiser are dependent upon rotational speed. As one would expect, the lower the operating pressure of the system, the stronger the dependency. Drum diameter, however, has no detectable effect on this dependency which is shown in Fig.6 for a 4 x 2 mm nozzle system for diameters ranging from 2" to 6". The flow changes at low rotational speeds are presumably those due to the type of vortex system existing inside the drum. At high rotational speeds the flow rate follows a square root dependency on operating pressure.

#### 4.4 Spray characteristics

Initial log-log plots of spray S.M.D. against rotational speed for different diameter drums, showed a pronounced effect of drum



diameter. The inference from these plots was that the drum peripheral velocity was a correlating parameter. However, resulting plots showed this to be not quite true. A liquid flow rate effect was observed and it became apparent that a better correlation could be obtained if the liquid discharge velocity was used instead of peripheral velocity. Resultant correlations were exceptionally good above 200 ft/sec. discharge velocity. Below this velocity a nozzle diameter effect was apparent, smaller diameters giving smaller droplets. The results of these correlations for kerosine and water show that the S.M.D. of these sprays were inversely proportional to the liquid discharge velocity above 200 ft/sec.

### Discussion

The results of these studies have shown the effect of major variables on the performance of the drum atomiser. The mean droplet diameter of the spray produced was found to be closely related to the liquid discharge velocity which, to a first approximation, could be taken as the peripheral velocity of the drum. Unlike the swirl type atomiser the mean droplet diameter of the spray produced by the drum atomiser is virtually independent of operating fuel pressure. This independence is of great advantage since it enables more moderate pressures to be used at the maximum fuel flow rate in conjunction with good atomisation at idling conditions.

At low rotational speeds, however, flow through the drum atomiser is subject to unusual flow phenomena, but since in most present-day fuel systems an auxiliary pressure drop device controls the flow rate (throttle orifice), then no unusual interaction between flow rate and rotational speed should exist.

Fuel distribution throughout the rotating system should be uniform, dispensing with the need, in conventional systems, for a distribution value. One may argue that with drum atomisers in some cases long, small diameter nozzles, will result in low discharge coefficients in addition to manufacturing difficulties. The experience of these studies, however, indicates that in most cases the discharge coefficients were better than



those of simplex atomisers. In addition, one has a much greater flexibility with the number of nozzles used on the drum atomiser than with conventional systems. The symmetry of the spray in an annular combustion chamber associated with the drum atomiser should result in a more even temperature distribution which could possibly be maintained to the turbine entry stage. There is, however, always a necessity for an annular combustion chamber with the drum atomiser or any centrifugal injection system. Hence realistic testing can only be achieved on full scale chambers fed with fuel from centrifugal atomiser. Whereas for small turbojet engines this can be done, one may find considerable increases in expense if testing is extended to larger engines.

### Conclusions

- (a) The spray quality of the drum atomiser is virtually independent of operating fuel pressure. The greatest influencing factor on the Sauter Mean Diameter of the spray being peripheral velocity of the drum.

$$\text{S.M.D. (microns)} = \frac{13,000}{V_{\text{PERIPHERAL}} \text{ (ft/sec.)}}$$

(FOR KEROSENE)

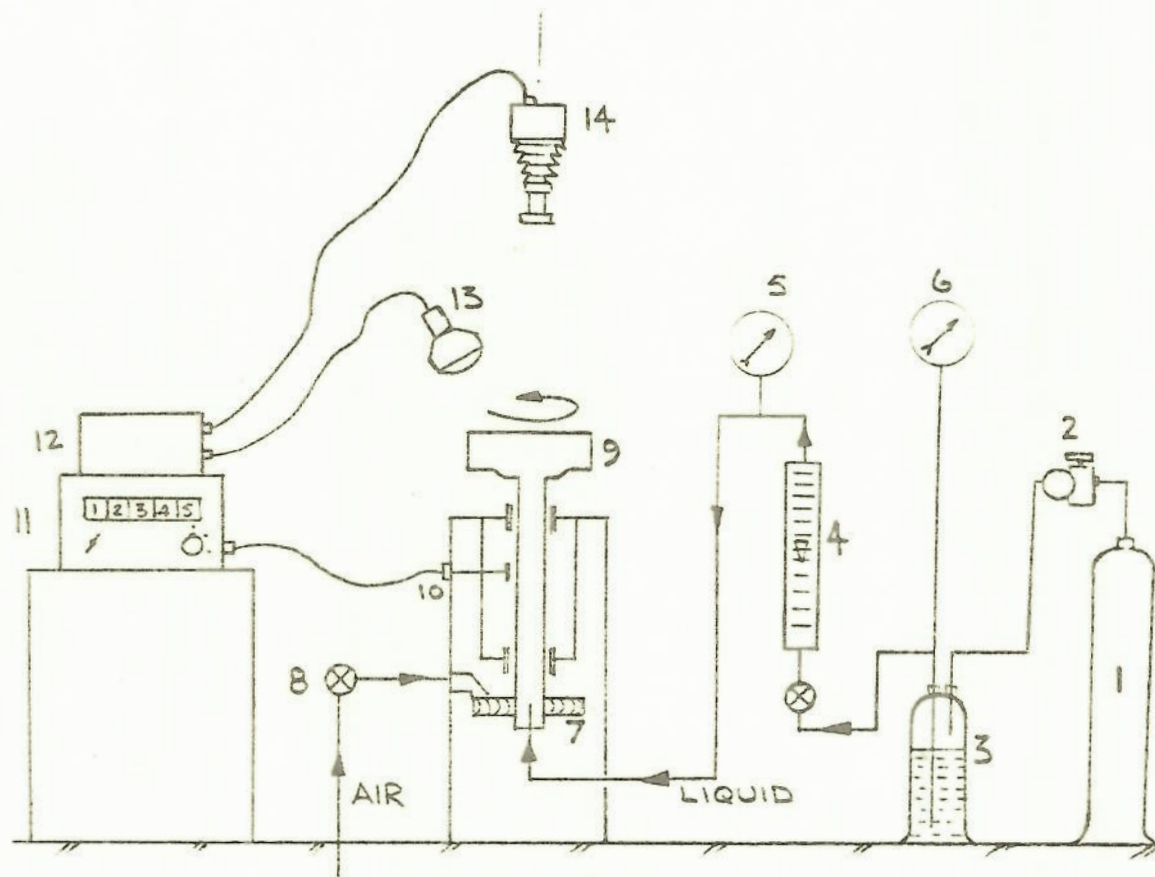
- (b) Drum atomisers offer considerable reductions in complexity, weight and cost in engine fuel systems, but are confined in application to annular combustion systems.
- (c) At high rotational speeds the flow through drum atomisers obeys the normal square root pressure drop relationship. At low speeds, particularly at low operating pressure, rotational speed modifies the relationship transiently.



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La Recherche Aeronautique No.66 Sept-Oct. 1958. (A rough translation is given in Reference 4).

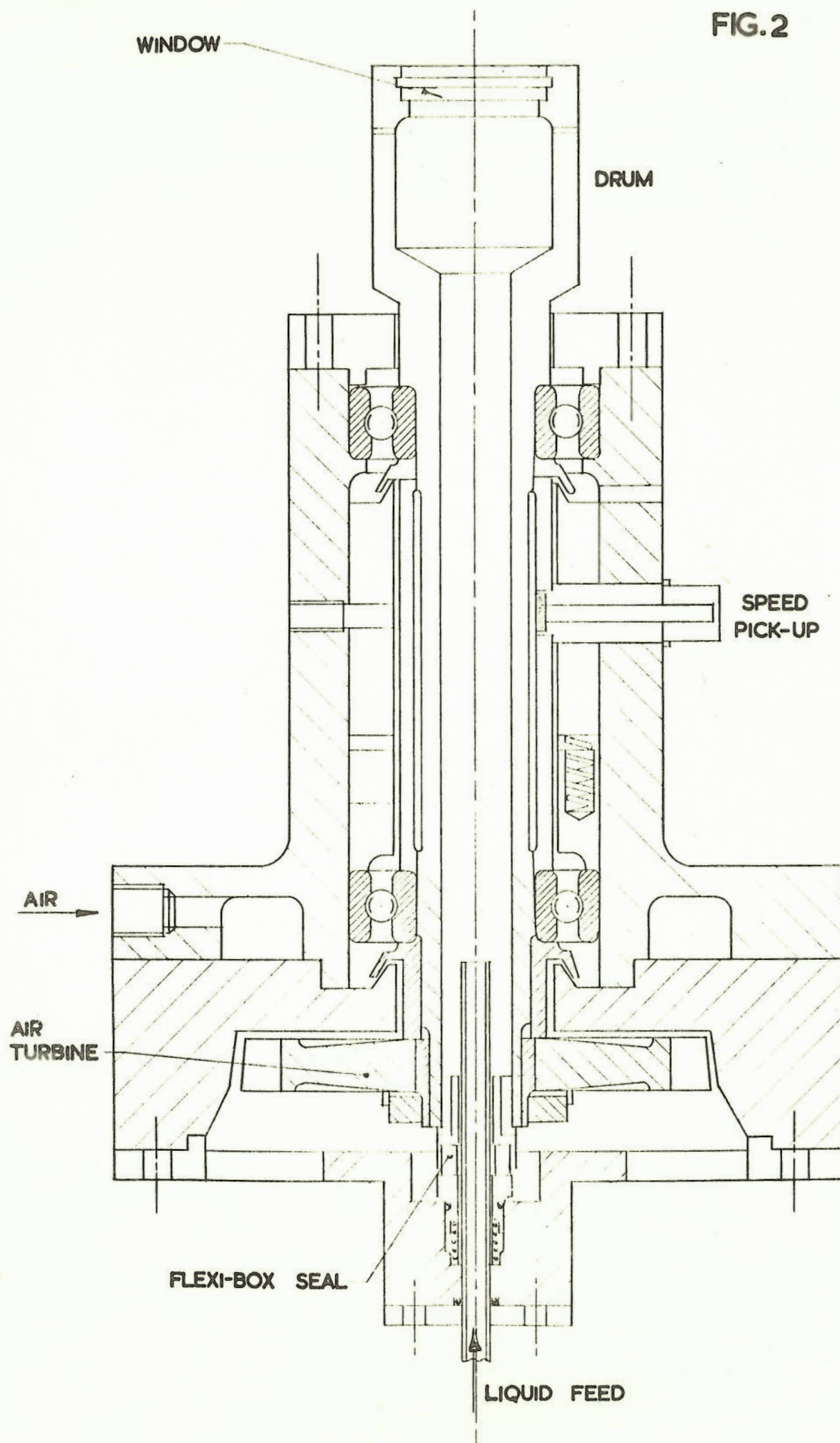
1. COMPRESSED AIR BOTTLE
2. PRESSURE REGULATOR
3. LIQUID BOTTLE
4. ROTAMETER
5. PRESSURE GAUGE
6. " "
7. AIR TURBINE
8. AIR CONTROL COCK
9. DRUM ATOMISER
10. SPEED PICK-UP
11. COUNTER
12. STROB-SYNCHRONIZER
13. STROB LAMP
14. CAMERA



SCHEME OF DRUM ATOMISER RIG.



FIG. 2



DRUM ATOMIZER ASSEMBLY.

# DRUM CONFIGURATIONS.

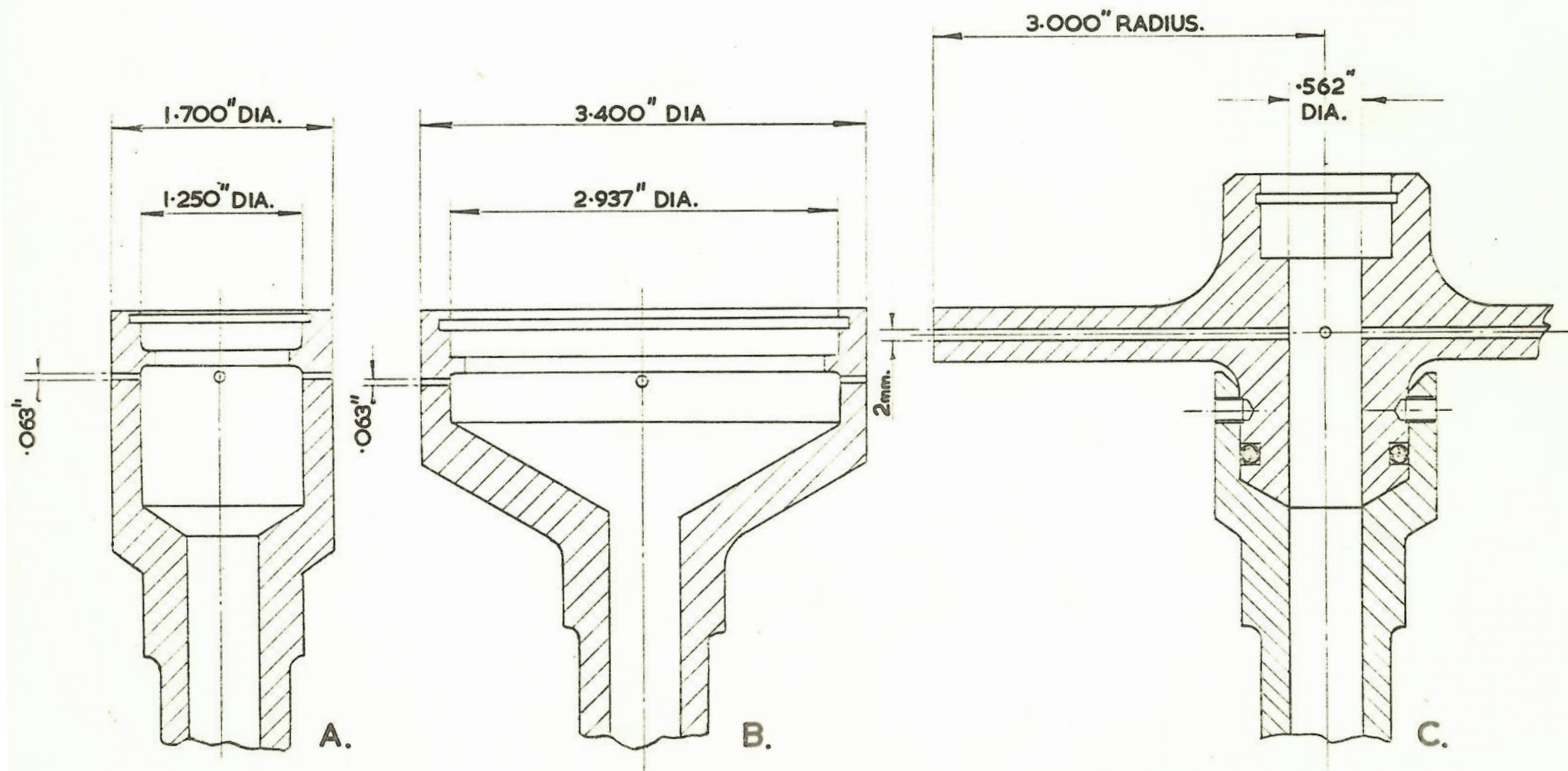
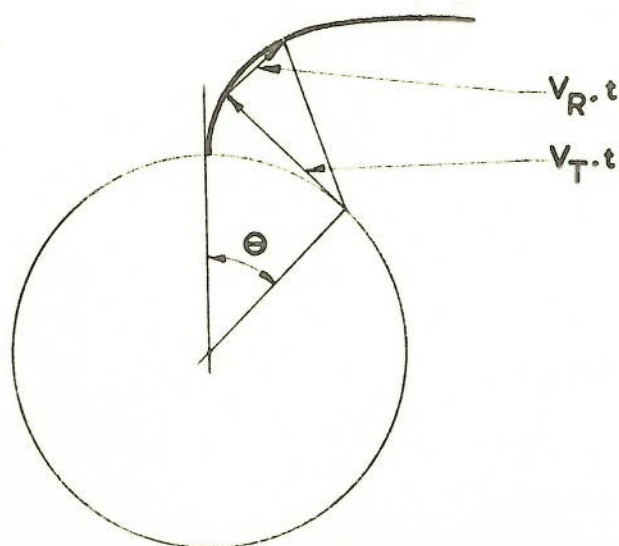
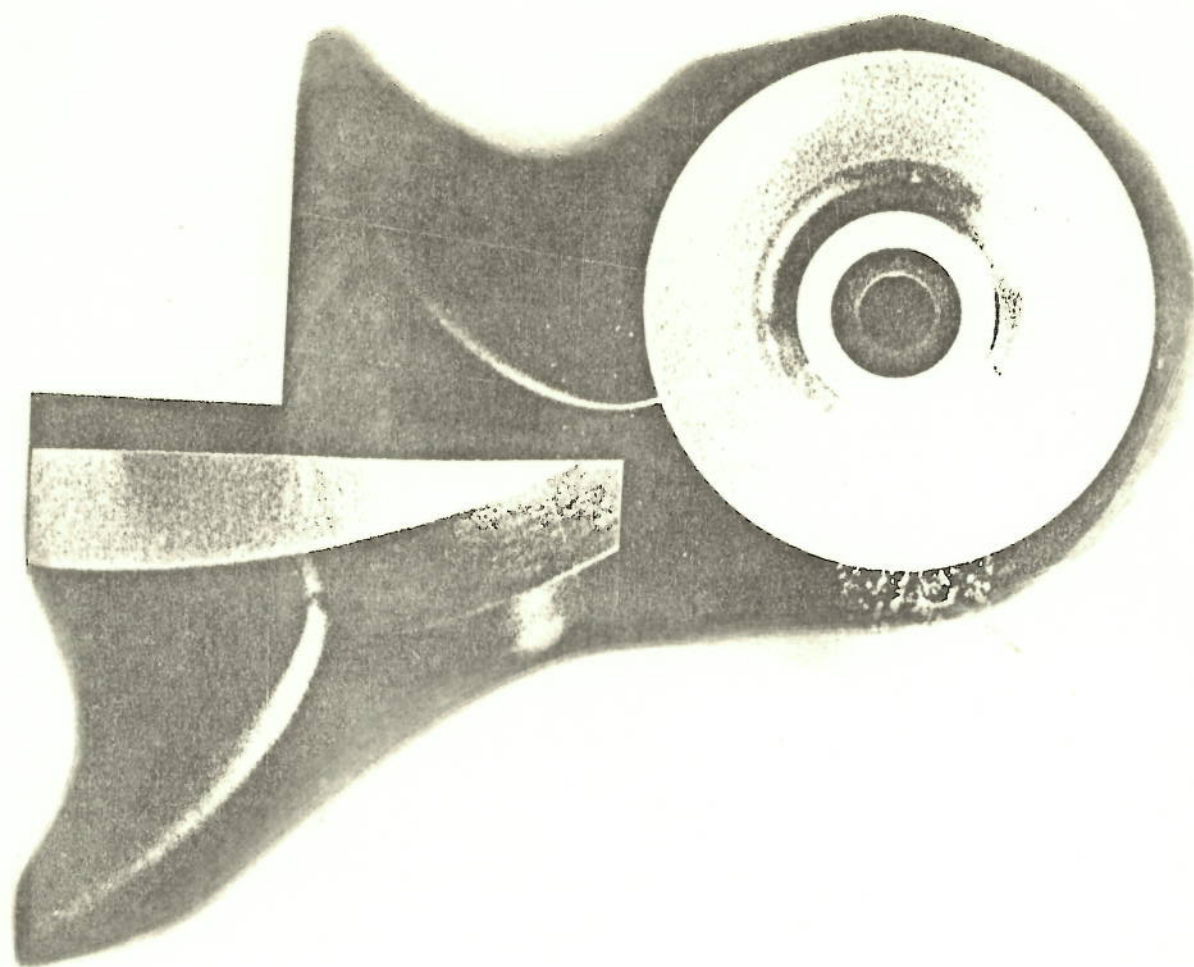


FIG.3.



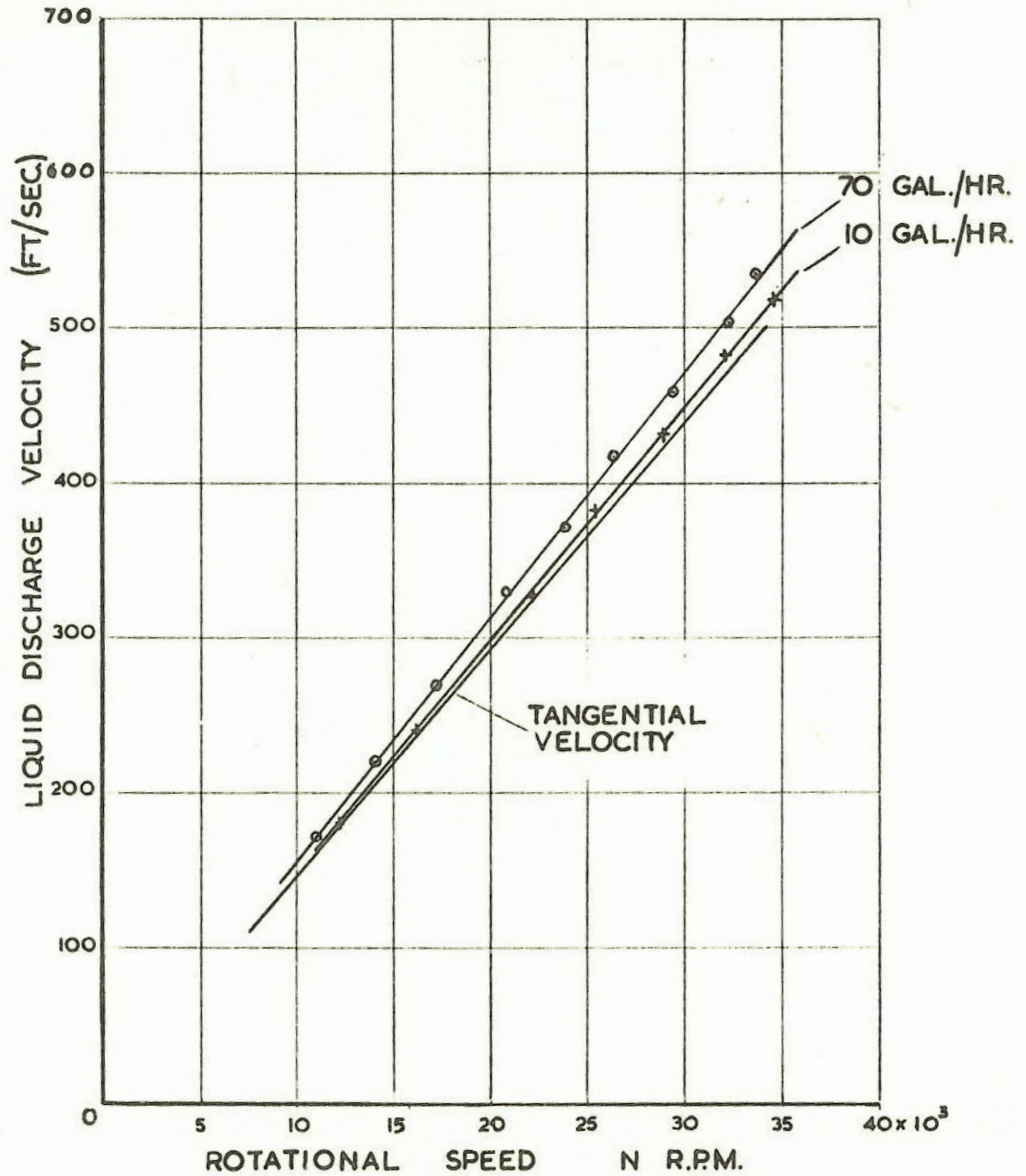
FIG. 4



ROTATING NOZZLE DISCHARGE VELOCITY.

FIG. 5

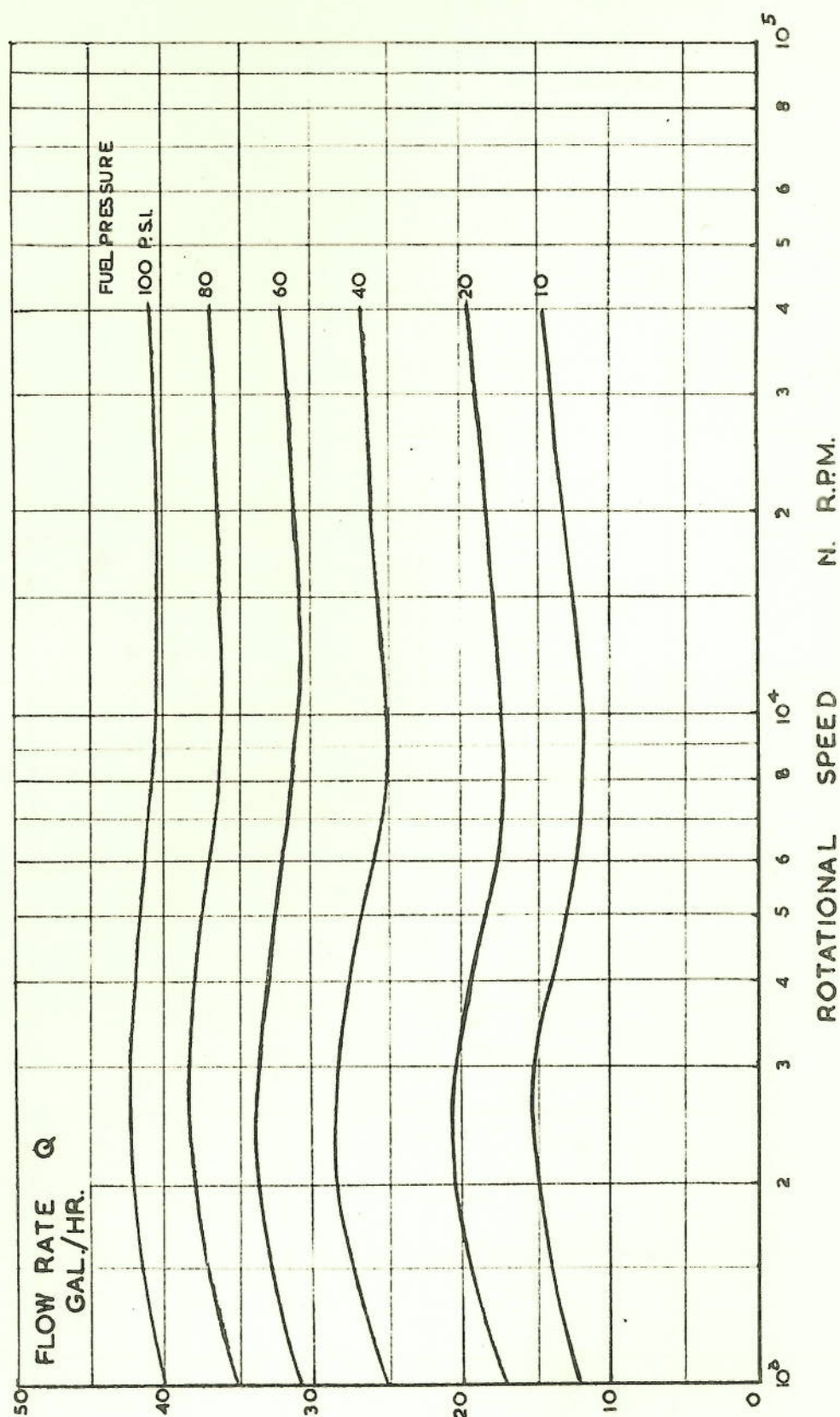
3.4" DIA. DRUM  
1/16" DIA. NOZZLES



TYPICAL VARIATIONS IN LIQUID  
DISCHARGE VELOCITY

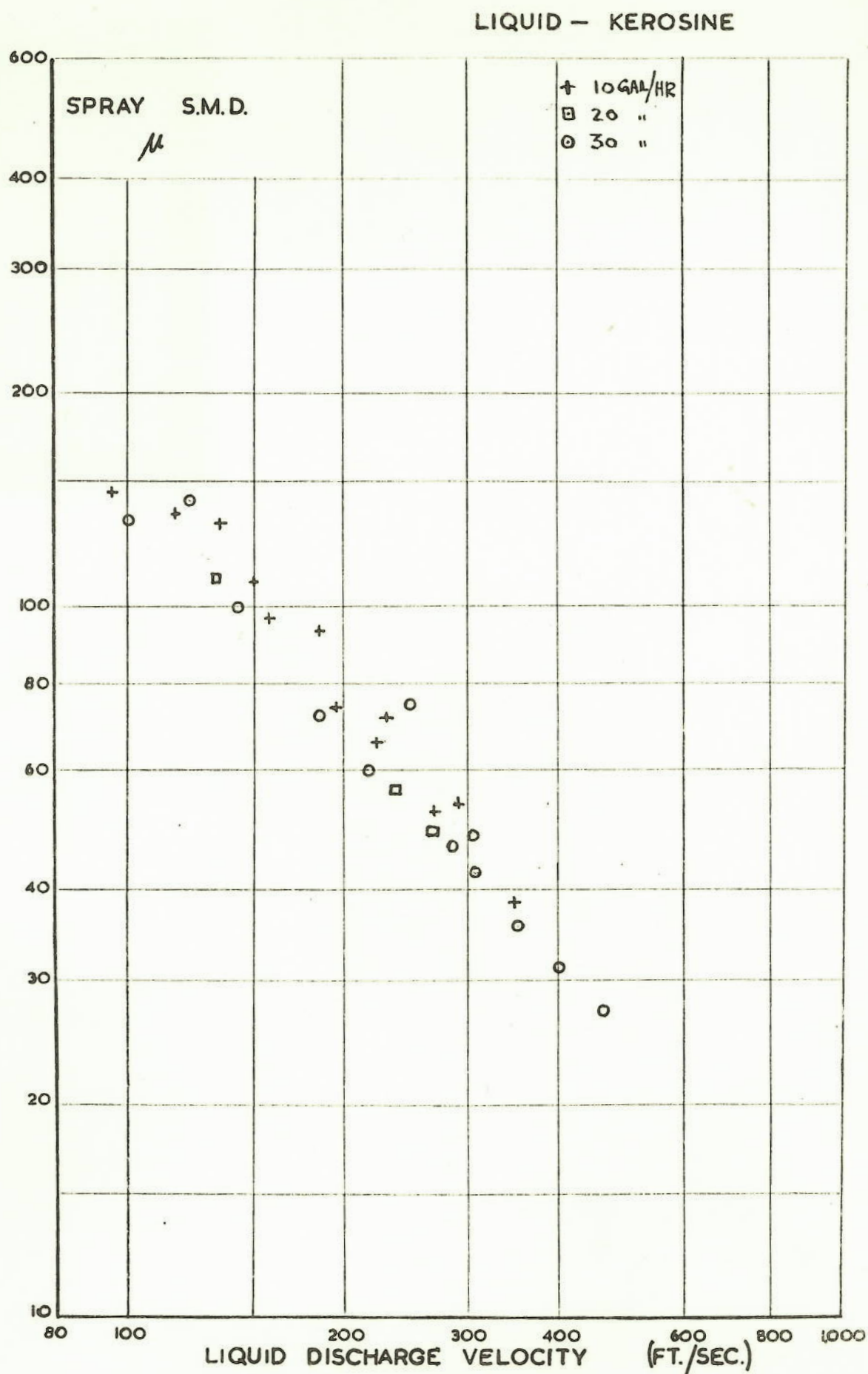


FIG.6



TYPICAL FLOW CHARACTERISTICS

FIG. 7



SPRAY CHARACTERISTICS